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MSTRIP2: Parameters of Microstrip Transmission Lines and of Coupled Pairs of Lines — 1978 Version and Its Application

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FOR THE COMMANDER

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MSTRIP2: PARAMETERS OF MICROSTRIP TRANSMISSION LINES AND OF COUPLED PAIRS OF LINES — 1978 VERSION AND ITS APPLICATION

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ABSTRACT

MSTRIP has undergone a succession of improvements since its original publication in 1968. Performance of the 1974 and later versions relating to aspects including weakly coupled (<-30 dB)pairs, low shield heights (closer than substrate thickness), and extremely low-impedance lines will be discussed. A FORTRAN list of the 1978 version is appended.

TABLE OF CONTENTS

MSTRIP2: PARAMETERS OF MICROSTRIP TRANSMISSION LINES AND OF COUPLED PAIRS OF LINES - 1978 VERSION AND ITS APPLICATION

I. INTRODUCTION

The "quasi-TEM" numerical analysis of the normal modes of propagation on coupled pairs of microstrip transmission lines named MSTRIP, published[1] by T.G. Bryant and J.A. Weiss in 1968, incorporated a Green's-function representation of "bound charge" at the upper surface of the dielectric substrate. For a wide range of applications, generally those in which the cross-sectional dimensions are small enough relative to wavelength, the accuracy of this method is very good; in fact, results of MSTRIP have been widely cited over the years as a standard for assessment of the accuracy of other microstrip algorithms. MSTRIP has been used, apparently without modification, in commercially available linear circuit analysis packages.[2]

The principal approximations (other than the usual substitution of discrete in place of certain continuous variables) are (a) the quasi-TEM assumption, whereby the results of the analysis are all based on the determination of static capacitance, and (b) the assumption of zero thickness and perfect conductivity of the conductors. Numerous papers have appeared in which this basic analysis has been adopted as the starting point for determination of the influences of dispersive effects and of finite conductivity and thickness of the strips.

The program has had some revisions for improved speed, accuracy, and range of applicability during the years since its original publication. We present this report in order to bring to the attention of microstrip circuit users the current version of MSTRIP and its capabilities and to address some questions which have arisen in relation to recent application requirements.

In 1970 and 1971, an improved program was formulated[3,4] in which the tabulated dielectric Green's function was replaced by a Fourier-integral evaluation. This change resulted in a very substantial improvement in speed and simplicity, better accuracy, and removal of the limitations on the range of substrate dielectric constant values. It also introduced the option of including the influence of a shield, or upper ground plane, above the circuit surface. The geometry of the shielded, coupled pair of microstrip lines is illustrated in Fig.1. A detailed review of methods and results, with a FORTRAN list of the version of the program then current, was published[5] in 1974. Following some improvements made in 1978, the program name was modified to MSTRIP2. The FORTRAN source of this program is shown in the Appendix.

In more recent times, users have brought up questions relating to the applicability and accuracy of MSTRIP for specific application requirements. Examples: the questions of upper limits on substrate dielectric constant and on strip widths; usability of the program for shielded microstrip with the

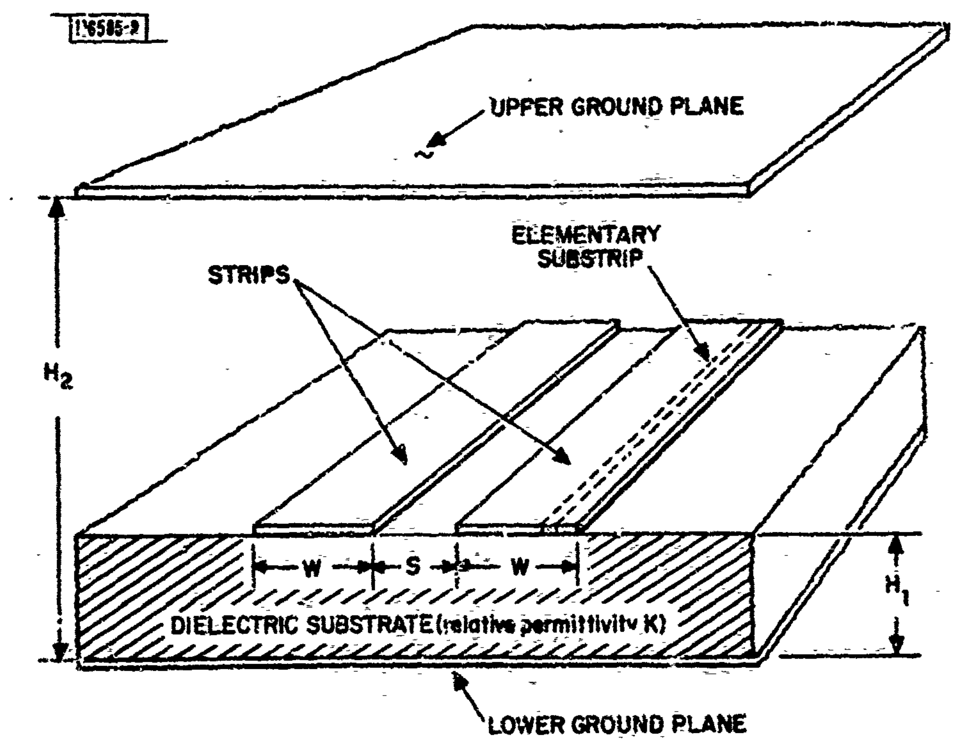

Fig.1. Shielded microstrip structure.

shield very close to the substrate surface ($H_2/H_1 < 2$); the accuracy of the program in cases of very weakly coupled pairs of lines, for which the differences between the two normal-mode characteristic impedances and velocities, which determine the backward- and forward-wave coupling coefficients, are very small.

Applications of these unusual microstrip structures have arisen in various contexts. For example, low-impedance (hence wide-line) transmission lines are needed to match the low impedance of Josephson-junction logic elements in superconducting computers.[6] Low shield heights can be used to correct the even- and odd-mode velocity differences of coupled lines on anisotropic dielectrics such as sapphire.[7] Weakly coupled pairs of lines are used as directional couplers in large time-bandwidth dispersive filters.[8]

In the following sections, information is presented relating to such structures and to some tests of accuracy of the program which their consideration provides.

II. SUBSTRATE DIELECTRIC CONSTANT

Nothing in MSTRIP2 imposes a limit on the substrate dielectric constant K. The program has served successfully with K values from 1 to 6000 (in fact, values of K less than unity have been used in order to represent an inverted structure - see Sec.III).

III. APPLICATION TO CASES OF A CLOSELY SPACED SHIELD

For values of H_2/H_1 less than 2 (see Fig.1), the gap between the shield and circuit surface is smaller than the substrate thickness. In such cases, MSTRIP2 loses accuracy. For example, with $H_2/H_1 = 1.25$, $S/H_1 = 3.5$, $W/H_1 = 0.50$, and $K = 9.6$ (alumina), MSTRIP2 gives the physically unreasonable result that $Z_{oe} < Z_{oo}$.

TABLE I

TRANSFORMATION FROM STANDARD TO INVERTED COMPUTATION
IN THE CASE OF A CLOSELY SPACED SHIELD*

Unprimed: Parameters of interest as used in the standard computation (Fig.1).

Primed: Input/output parameters to be used to analyze the same structure by inverted computation.

$$R \equiv \frac{H_2}{H_1}$$

MSTRIP Input:

$$H_1' = H_2 - H_1 \qquad \left(\frac{W}{H_1}\right)' = \frac{W/H_1}{R-1}$$

$$R' = \frac{R}{R-1} \qquad \left(\frac{S}{H_1}\right)' = \frac{S/H_1}{R-1}$$

$$K' = \frac{1}{K}$$

To interpret MSTRIP output, transform tabulated values as follows. (Primed variables are output of the inverted computation, unprimed variables are those of the actual structure of interest.)

$$K_{eff} = K'_{eff}K \qquad Z = \frac{Z'}{\sqrt{K}}$$

$$C = C'K \qquad V = \frac{V'}{\sqrt{K}}$$

*See Sec.III.

This deficiency may be circumvented by inverting the problem, placing the gap ($K = 1$) on the bottom, and the substrate ($K > 1$) above, so that $H_2/H_1 > 2$. Because MSTRIP incorporates the assumption that the gap has a dielectric constant of unity, the input and output parameters must be transformed according to the system shown in Table I.

Using this procedure as a check, it may be verified that MSTRIP2 is accurate to H_2/H_1 values less than 1.5. For example, for a 50-Ω pair of coupled lines on sapphire with $H_2/H_1 = 1.5$, $S/H_1 = 3.5$, the two methods agree to within 0.01 percent in impedances and 0.02 percent in velocities. The two agree to within 0.04 dB in backward coupling, even though it is a weak -64 dB. With the shielding height reduced to $H_2/H_1 = 1.25$, the discrepancy in impedance between the standard computation and the inverted structure increases to 0.3 percent, unacceptable for the calculation of coupling in this weakly coupled structure.

IV. COMPARISON WITH ANALYTIC CALCULATION

In the special case $H_2/H_1 = 2$, the quasi-static electric field in the shielded (coupled) microstrip structure with zero conductor thickness may be shown to be symmetric about the dielectric/air interface. Consequently, the quasi-static characteristics of the microstrip (MS) are identical to those of a balanced stripline (SL) structure of the same dimensions filled with a material of dielectric constant $K_{SL} = (1/2)\,(K_{MS} + 1)$.

This equivalency provides a convenient check on shielded microstrip calculations, as analytical expressions for coupled striplines are well known. In Table II are shown the results of calculations for several values of S/H_1 and W/H_1, using MSTRIP and MSTRIP2 for shielded microstrip ($K_{MS} = 9.6$) and an analytic approximation for the stripline ($K_{SL} = 5.3$). A transcendental approximation valid to 8 parts in 10^6 compared to the exact elliptic integral expression for stripline impedances was used, given as Eqs.6.3.1, 6.3.2, 3.2.7, and 3.2.8 in the book by Gunston.[9] Both MSTRIP and MSTRIP2

TABLE II

IMPEDANCE, COUPLING, AND EFFECTIVE DIELECTRIC CONSTANT VALUES CALCULATED BY MSTRIP, MSTRIP2, AND BALANCED STRIPLINE METHODS, $H_2/H_1 = 2$; $K = 9.6$ FOR MICROSTRIP, 5.3 FOR STRIPLINE

		Z_{oe} (Ω)			Z_{oo} (Ω)			$-k_B$ (dB)			
S/H_1	W/H_1	MSTRIP	MSTRIP2	Strip-line	MSTRIP	MSTRIP2	Strip-line	MSTRIP	MSTRIP2	Strip-line	$(K_{eff})_{even}$ (MSTRIP)
0.5	0.3	90.29	89.82	89.36	58.26	58.26	57.77	13.3	13.4	13.4	5.346
	0.8	57.72	57.25	56.84	40.60	40.60	40.07	15.2	15.4	15.2	5.372
	1.3	42.94	42.46	42.12	32.43	32.43	31.90	17.1	17.5	17.2	5.397
1.0	0.3	81.75	81.27	80.81	67.29	67.29	66.81	20.3	20.5	20.5	5.351
	0.8	53.55	53.07	52.65	45.63	45.63	45.16	22.0	22.5	22.3	5.378
	1.3	40.55	40.07	39.70	35.60	35.60	35.16	23.7	24.6	24.3	5.403
2.0	0.3	76.25	75.77	75.31	72.88	72.89	72.42	32.9	34.2	34.2	5.354
	0.8	50.69	50.22	49.78	48.68	48.68	48.23	33.9	36.2	36.0	5.382
	1.3	38.87	38.39	38.00	37.47	37.47	37.06	34.7	38.3	38.1	5.407
4.0	0.3	74.87	74.39	73.93	74.27	74.27	73.80	47.9	61.5	61.5	5.355
	0.8	49.96	49.48	49.05	49.42	49.42	48.98	45.2	63.5	63.3	5.383
	1.3	38.43	37.95	37.55	37.91	37.91	37.51	43.4	65.6	65.3	5.408
10.0	0.3	74.81	74.33	73.87	74.33	74.33	73.87	49.9	>100	>100	5.355
	0.8	49.93	49.45	49.01	49.45	49.45	49.01	46.4	>100	>100	5.383
	1.3	38.41	37.93	37.53	37.93	37.93	37.53	44.1	>100	>100	5.408

were run with M = 20 substrips per strip. In addition to the even- and odd-mode impedances, the backward-wave coupling strength for a quarter-wave length of line is shown, given by the expression

$$k_B \text{ (dB)} = 20 \log_{10} \frac{Z_{oe} - Z_{oo}}{Z_{oe} + Z_{oo}} \quad .$$

The even-mode effective dielectric constant given by MSTRIP is also shown. The odd-mode constant given by MSTRIP and both mode constants given by MSTRIP2 exhibit the proper value of 5.3.

It is evident that both versions of MSTRIP give reliable impedance and backward coupling values for k_B in the range of stronger coupling ($S/H_1 < 1$, $k_B > -25$ dB). Impedances are within 1 Ω of the stripline values and coupling strengths are within 1 dB. In the -30- to -40-dB range ($S/H_1 \sim 2$) MSTRIP2 retains its accuracy in coupling strength, while errors of more than 3 dB appear in MSTRIP. For $S/H_1 > 2$, MSTRIP rapidly loses accuracy, never predicting coupling weaker than -50 dB. MSTRIP2 remains within a few tenths of one decibel of the stripline value.

It is noteworthy that, over the whole range of S/H_1 and W/H_1 tested, the odd-mode impedances given by MSTRIP and MSTRIP2 are identical and exceed the stripline values by 0.4 to 0.5 Ω. MSTRIP2 gives Z_{oe} values which are similarly 0.4 to 0.5 Ω higher than stripline values, while MSTRIP gives Z_{oe} values about 1 Ω too high. Thus, even- and odd-mode impedance errors given by MSTRIP2 track each other, giving accurate coupling values, while a roughly 0.5-Ω difference exists between the MSTRIP even- and odd-mode impedance errors, resulting in large errors in coupling strength for weakly coupled lines.

There is also a significant error in the even-mode effective dielectric constant given by MSTRIP. This error is positive, opposite in sign to that expected on the basis of the Z_{oe} error. The error results in a predicted even-mode phase velocity less than that of the odd mode. On this basis, a forward coupling strength of -40 to -50 dB over a 90° line segment would be predicted for all lines considered in Table I.

MSTRIP is adequate for design of couplers tighter than -25 dB, although it may give inaccurate values of directivity. For calculation of cross talk between closely spaced lines in applications such as MICs where space is at a premium, the current, more accurate version, MSTRIP2, is needed.

V. APPLICATION TO EXTREMELY LOW-IMPEDANCE LINES

In 1980 an MSTRIP user, J.C. Cozzie, pointed out[10] a flaw which he had discovered when he attempted to determine microstrip parameters for extremely low-impedance lines: $Z_o < 3\ \Omega$, which requires strip widths of $W/H_1 > 70$ in the case $K = 2.45$ which was of interest to him. Cozzie located the flaw in the subroutine MGREEN, recognized it as a consequence of an approximation embedded in the integration procedure, and described how he eliminated it with changes including the substitution of a Gaussian quadrature procedure. (Cozzie was working with the 1971 or 1974 version of MSTRIP. By coincidence we had also converted MGREEN to Gaussian quadrature integration, calling IBM Scientific Subroutine DQG32, in the 1978 version.)

At Cozzie's instigation, we modified certain details of MGREEN to remove the flaw. At the time, we had the following further thoughts regarding very wide strips. First: if the scale of dimensions is such that the width becomes comparable to a half-wavelength (in a medium of dielectric constant K_{eff} as evaluated by MSTRIP2) in the frequency range of interest, then spurious propagation effects and coupling problems are to be expected. In that case, it would probably be advisable to seek some alternative means to obtain the circuit function contemplated. Second: for widths of $W/H_1 > 20$ or so, very accurate results can be obtained by decomposing the strip capacitance into the sum of W/H_1 times a parallel-plate part per unit increment of W/H_1 plus an edge contribution. Once suitable limiting values of those two capacitance parameters have been determined by a few trials, the microstrip parameters for all cases of wider strips with the same substrate K value can be quickly determined. Cozzie noted this suggestion and briefly presented his version of it in his paper.[10]

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10. J.C. Cozzie: "Low Impedance Microstrip Calculations Using MSTRIP," IEEE Trans. Microwave Theory Tech. MTT-28, 1228 (November 1980).

APPENDIX

```
C***********************************************************************
C
C                              -MSTRIP2-
C
C          PARAMETERS OF MICROSTRIP TRANSMISSION LINES AND
C                OF COUPLED PAIRS OF MICROSTRIP LINES
C
C          IMPROVED -- VERSION OF AUG. 1 , 1978
C
C REFERENCES - 1. T.G. BRYANT AND J.A. WEISS, IEEE TRANS MTT-16 1021
C                 (DECEMBER 1968).
C              2. J.A. WEISS AND T.G. BRYANT, ELECTRONICS LETTERS
C                 VOL. 5 P. 517 (OCTOBER 16, 1969).
C              3. J.A. WEISS AND T.G. BRYANT, ELECTRONICS LETTERS
C                 VOL. 6 P. 462 (JULY 23, 1970); SEE ALSO ERRATUM,
C                 ELECTRONICS LETTERS VOL. 6 P. 560 (AUGUST 20,1970).
C              4. T.G. BRYANT AND J.A. WEISS, IEEE TRANS MTT-19 418
C                 (APRIL, 1971).
C              5. J.A. WEISS, ADVANCES IN MICROWAVES, VOL. 8,
C                 PP. 295-320; ACADEMIC PRESS, 1974.
C
C     FOR MICROSTRIP COMPRISING - A DIELECTRIC SUBSTRATE OF RELATIVE
C DIELECTRIC PERMITTIVITY K AND THICKNESS H1 LYING ON A CONDUCTING
C GROUND PLANE; A SINGLE STRIP OF WIDTH W OR TWO PARALLEL STRIPS OF
C EQUAL WIDTH W WITH INNER EDGES DISTANCE S APART, LYING ON THE UPPER
C SURFACE OF THE SUBSTRATE; THICKNESS OF THE STRIP MATERIAL ASSUMED
C TO BE NEGLIGIBLE; AN UPPER GROUND PLANE LOCATED PARALLEL TO AND
C DISTANCE H2 ABOVE THE LOWER GROUND PLANE (OPTIONAL).
C
C     THE PROGRAM COMPUTES THE FOLLOWING TRANSMISSION-LINE PARAMETERS
C FOR A SINGLE STRIP OR FOR BOTH THE EVEN AND ODD MODES OF A COUPLED
C PAIR OF STRIPS -
C
C          CHARACTERISTIC IMPEDANCE;
C          PHASE VELOCITY;
C          EFFECTIVE DIELECTRIC CONSTANT K-EFF;
C          CAPACITANCE PER UNIT LENGTH PER STRIP (OPTIONAL).
C
C    THE CALCULATION EMBODIES THE QUASI-STATIC APPROXIMATION, AS
C EXPLAINED IN REFERENCE 1; THE APPROXIMATION IS ACCURATE PROVIDED
C H1 IS NO GREATER THAN A FEW PERCENT OF THE WAVELENGTH IN AN UN-
C BOUNDED MEDIUM OF PERMITTIVITY K.
C
C    THE PROGRAM ACCEPTS ANY VALUE OF K, S/H1, AND W/H1.
C
C     INPUT AND OUTPUT MEDIA ARE IDENTIFIED IN THE PROGRAM BY THE
C FOLLOWING NAMES - INPUT (USUALLY A CARD READER), IV; OUTPUT (USU-
C ALLY A LINE PRINTER), IW.
C
```

```
C      INPUT DATA - THE INPUT DATA CARD IS WRITTEN IN NAMELIST FORMAT
C  AND CONTAINS SIX DECIMAL NUMBERS AND ONE INTEGER NUMBER, ALL
C  SEPARATED BY COMMAS, AS IN THE FOLLOWING EXAMPLE.
C
C &CONST WH1=0.1,DELW=0.2,NT=20,R=0.0,DIEK=9.6,SH1=0.4,AIR=1.0, &END
C
C  THIS CARD SPECIFIES THE VALUES OF PROGRAM VARIABLES HAVING THE FOL-
C  LOWING NAMES -
C
C  WH1.DELW,NT,R,DIEK,SH1,AIR
C
C  WH1 IS THE STARTING VALUE OF W/H1; DELW IS THE INCREMENT OF W/H1;
C  NT IS THE NUMBER OF LINES IN THE OUTPUT TABLE (EQUAL TO THE NUM-
C  BER OF VALUES OF W/H1); R IS THE GROUND PLANE RATIO H2/H1 (FOR THE
C  OPTION OF NO UPPER GROUND PLANE, SET R = 0.0); DIEK IS THE RELA-
C  TIVE DIELECTRIC PERMITTIVITY K OF THE SUBSTRATE; SH1 IS THE VALUE
C  OF S/H1; AIR TAKES ONE OF THE TWO VALUES 0.0 (SINGLE STRIP) OR
C  1.0 (COUPLED STRIPS). THUS IN THE EXAMPLE THE OUTPUT TABLE WILL RE-
C  FER TO THE EVEN AND ODD MODES OF COUPLED STRIPS WITH SPACING S/H1
C  = 0.4 ON SUBSTRATE OF PERMITTIVITY K = 9.6, NO UPPER GROUND PLANE,
C  AND WILL LIST 20 LINES, FROM W/H1 = 0.1 THROUGH W/H1 = 2.0 IN
C  STEPS OF 0.2.
C
C      OUTPUT - THE OUTPUT FORMAT IS ILLUSTRATED IN THE FOLLOWING
C  TABLE SHOWING THE FIRST LINE OF OUTPUT DATA FOR THE ABOVE EXAMPLE.
C
C
C   H2/H1 =  0.0      K = 9.60     COUPLED STRIPS     S/H1 = 0.4
C
C
C  W/H1       ZO(E)     ZO(O)       V(E)     V(O)     K-EFF(E) K-EFF(O)
C                  OHMS              E+08 M/SEC
C
C  0.100     141.210  77.250     1.214    1.299      6.102    5.328
C
C
C      SUBROUTINES REQUIRED - THE PROGRAM CALLS THREE SUBROUTINES OB-
C  TAINED FROM THE IBM SCIENTIFIC SUBROUTINE PACKAGE (SSP). THEY ARE
C  DGELS, SICI, AND DQG32. FOR DESCRIPTIONS AND LISTS OF THESE PROGRAMS
C  SEE THE IBM SSP MANUAL. IN ADDITION, THE PROGRAM INCLUDES FIVE SUB-
C  ROUTINES OF ITS OWN - OUTPUT, XGEN, AMAT, MPHI, AND MGREEN AND ONE
C  FUNCTION SUBPROGRAM  - GINT. NOTE ON THE IMPROVEMENT DATED AUG. 1,
C  1978: THE INTEGRATION SUBROUTINE DQG32 (32-POINT GAUSSIAN QUAD-
C  RATURE METHOD) REPLACES THE SUBROUTINE DQSF(SIMPSON'S RULE) ,
C  RESULTING IN ACCURACY SUBSTANTIALLY BETTER THAN ONE PERCENT IN ALL
C  CASES TESTED. REVISIONS AND TESTS PERFORMED BY R. C. LEWIS.
C
C      NOTE ON DIMENSION REQUIREMENTS - FOR THE DETERMINATION OF
C  CHARGE DISTRIBUTION EACH STRIP IS DIVIDED INTO M SUBSTRIPS. IN
C  THE PRESENT PROGRAM M = 20, BUT THE PARAMETER M CAN BE INCREASED
```

```
C  FOR IMPROVED ACCURACY OR REDUCED FOR IMPROVED SPEED OF EXECU-
C  TION. THE DIMENSIONS OF THE VARIABLES DEPEND ON THE VALUE OF M
C  AS FOLLOWS -
C
C       V(M),AUX(M-1),X(3M-1),PHI(3M-1),A(M(M+1)/2),B(M(M+1)/2)

C
C**************************************************************************
C
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION V(20),AUX(19),GO(2)
      COMMON/DIM/X(59),PHI(59),A(210),B(210)
      NAMELIST/CONST/WH1,DELW,NT,R,DIEK,SH1,AIR
      DATA GO/'Y','N'/
      CALL TIMES(DATE,TIME)
      IV=5
      IW=1
      M=20
      N=1
      WRITE(IW,104)
  801 DO 901 NREP=1,25
      EPS=1.0E-07
      IF(NREP .EQ. 1) GO TO 91
 92   WRITE(6,102)
      READ(IV,103) GOYN
      IF(GOYN .EQ. GO(1)) GO TO 91
      IF(GOYN .NE. GO(1) .AND. GOYN .NE. GO(2)) GO TO 92
      GO TO 999
 91   WRITE(6,101)
      READ(IV,CONST)
      IF(AIR) 38,7,8
 7    WRITE(IW,105) R,DIEK
      WRITE(IW,106)
      GO TO 802
 8    WRITE(IW,107) R,DIEK,SH1
      WRITE(IW,108)
  802 DO 902 K=1,NT
      AK=K
      WH=WH1+(AK-1.0)*DELW
      CALL XGEN(M,WH,SH1)
      NN=AIR+1
      ADIEK=DIEK
  803 DO 903 IJ=1,2
      IF(IJ.EQ.1) DIEK=1.0
      IF(IJ.EQ.2) DIEK=ADIEK
      IF(R.EQ.0.0.AND.DIEK.EQ.1.0) GO TO 39
      CALL MGREEN(M,WH,SH1,DIEK,R)
      GO TO 804
 39   CALL MPHI(WH,M,AIR)
  804 DO 903 JJ=1,NN
      CALL AMAT(AIR,M)
      DO 23 I=1,M
```

```
23    V(I)=1.0
      IF(JJ .EQ. 1) CALL DGELS(V,A,M,N,EPS,IER,AUX)
      IF(JJ .EQ. 2) CALL DGELS(V,B,M,N,EPS,IER,AUX)
      IF(IER.NE.0) WRITE(IW,111) IER,EPS
111   FORMAT(' IER= ',I3,', IN SUBROUTINE DGELS, SO THE CHARGE DENSITY
     2 COULD NOT BE CALCULATED TO THE PRECISION OF ',E13.6,' DIGITS')

      CAPSUM=0.0
      DO 21 I=1,M
21    CAPSUM=CAPSUM+V(I)
      CC=CAPSUM*111.256
      IF(JJ .EQ. 1 .AND. IJ .EQ. 1) CAP1E=CC
      IF(JJ .EQ. 1 .AND. IJ .EQ. 2) CAPKE=CC
      IF(JJ .EQ. 2 .AND. IJ .EQ. 1) CAP1O=CC
      IF(JJ .EQ. 2 .AND. IJ .EQ. 2) CAPKO=CC
 903  CONTINUE
      CALL OUTPUT(CAP1E,CAPKE,CAP1O,CAPKO,WH,IW,NN)
 902  CONTINUE
      WRITE(IW,110) DATE,TIME
      WRITE(IW,199)
      GO TO 901
38    WRITE(6,109)
 101  FORMAT(/,3X,'CONST:  WH1,DELW,NT,R,DIEK,SH1,AIR  ?',/)
 102  FORMAT(/,3X,'CONTINUE? (''YES'' OR ''NO'')',/)
 103  FORMAT(A1)
 104  FORMAT('1',//,5X,'J.A. WEISS, ',
     2    'ADVANCES IN MICROWAVES, VOL. 8,',/7X,'PP. 295-320; ',
     3    'ACADEMIC PRESS, 1974.',//,10X,'PARAMETERS OF MICROSTRIP ',
     4    'TRANSMISSION LINES',/,12X,'AND OF COUPLED PAIRS OF ',
     5    'MICROSTRIP LINES')
 105  FORMAT(//,11X,'H2/H1 = ',F6.3,5X,'K = ',F6.3,4X,'SINGLE STRIP')
 106  FORMAT(/,10X,'W/H1',12X,'ZO',14X,'V',12X,'K-EFF',11X,'C',/,
     2      10X,15X,'OHMS',8X,'E+08 M/SEC',23X,'PF/M',/)
 107  FORMAT(//3X,'H2/H1 = ',F6.3,4X,'K = ',F6.3,4X,'COUPLED STRIPS',
     2      5X,'S/H1 = ',F5.2)
 108  FORMAT(/,3X,'W/H1',6X,'ZO(E)',4X,'ZO(O)',6X,'V(E)',4X,'V(O)',4X,
     2      'K-EFF(E) K-EFF(O)',4X,'C(E)',5X,'C(O)',/18X,'OHMS',12X,
     3      'E+08 M/SEC',30X,'PF/M',/)
 109  FORMAT(//,' AIR SHOULD BE 0.0 OR +1.0',//)
 110  FORMAT(//,5X,2(A8,2X),/)
 199  FORMAT(///)
 901  CONTINUE
 999  CONTINUE
      CALL EXIT
      STOP
      END
C
C
      SUBROUTINE OUTPUT(CAP1E,CAPKE,CAP1O,CAPKO,WH,IW,NN)
C
      IMPLICIT REAL*8(A-H,O-Z)
      DATA C/2.99792458/
```

```
      EFFKE=CAPKE/CAP1E
      RKE=DSQRT(EFFKE)
      ZOE=1.0E+04/(C*CAP1E*RKE)
      VELE=(1.0/RKE)*C
      IF(NN. EQ. 1) WRITE(IW,101) WH,ZOE,VELE,EFFKE,CAPKE
      IF(NN .EQ. 1) GO TO 3
      EFFKO=CAPKO/CAP1O
      RKO=DSQRT(EFFKO)
      ZOO=1.0E+04/(C*CAP1O*RKO)
      VELO=(1.0/RKO)*C
      WRITE(IW,103) WH,ZOE,ZOO,VELE,VELO,EFFKE,EFFKO,CAPKE,CAPKO
  101 FORMAT(5(5X,F10.3))
  102 FORMAT(2X,F6.3,4X,F7.3,1X,F7.3,4X,F6.3,2X,F6.3,5X,F6.3,2X,F6.3)
  103 FORMAT(2X,F6.3,4X,F7.3,1X,F7.3,4X,F6.3,2X,F6.3,5X,F6.3,2X,F6.3,
     2     4X,F8.3,1X,F8.3)
    3 RETURN
      END
C
C
      SUBROUTINE XGEN(M,WH,SH1)
C
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/DIM/X(59),PHI(59),A(210),B(210)
      AM=M
      WHM=WH/AM
  801 DO 901 I=1,M
      AI=I
  901 X(I)=(AI-1.0)*WHM
      IF(SH1 .EQ. 0.0) GO TO 1
      MM=2*M-1
  802 DO 902 I=1,MM
      AI=I
  902 X(I+M)=AI*WHM+SH1
    1 RETURN
      END
C
C
      SUBROUTINE AMAT(S,M)
C
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/DIM/X(59),PHI(59),A(210),B(210)
  803 DO 903 I=1,M
      INDEX1=M+1-I
  804 DO 904 J=1,INDEX1
      NF1=0
  805 DO 905 K=1,J
  905 NF1=NF1+K
      NF2=0
      IF(I .LE. 2) GO TO 10
      INDEX2=I-2
  806 DO 906 L=1,INDEX2
  906 NF2=NF2+L
```

```
 10   N=NF1+NF2+(I-1)*J
      INDEX3=3*M+2*(1-J)-I
      A(N)=PHI(I)+S*PHI(INDEX3)
      B(N)=PHI(I)-S*PHI(INDEX3)
  904 CONTINUE
  903 CONTINUE
      RETURN
      END
C
C
      SUBROUTINE MPHI(WH,M,S)
C
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/DIM/X(59),PHI(59),A(210),B(210)
      AM=M
      INDEX1=3*M-1
      IF(S .EQ. 0.0) INDEX1=M
      EXWON=WH/(2.0*AM)
      WYWON=1.0D 00
  807 DO 907 K=1,INDEX1
      XO=X(K)
      EXP=XO+EXWON
      EXN=XO-EXWON
      WYP=2.0*WYWON
      PHI(K)=(EXN/(2.0*EXWON))*DLOG((EXN**2)/(EXN**2+WYP**2))-(EXP
     2  /(2.0*EXWON))*DLOG((EXP**2)/(EXP**2+WYP**2))+(WYP/EXWON)
     3  *(DATAN(EXP/WYP)-DATAN(EXN/WYP))
  907 CONTINUE
      RETURN
      END
C
C
      SUBROUTINE MGREEN(M,WH,SH1,DIEK,R)
C
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/DIM/X(59),PHI(59),A(210),B(210)
      COMMON /PASS/ R1,CO,BO,DIEK1
      EXTERNAL GINT
      AM=M
      R1=R
      DIEK1=DIEK
      CO=WH/AM*0.5
      X1=5.0
      INT=2
      H=X1/DFLOAT(INT)
      IF(SH1 .EQ. 0.0) MA=M
      IF(SH1 .NE. 0.0) MA=3*M-1
  808 DO 908  MM=1,MA
      BO=X(MM)
      YTOT=0.0D0
      XU=0.0
      XL=0.0
```

```
C
C       COMPUTE FIRST INTEGRAL
C
  809 DO 909 I=1,INT,1
      XU=XU+H
      CALL DQG32(XL,XU,GINT,YRESUL)
      YTOT=YTOT+YRESUL
      XL=XL+H
  909 CONTINUE
      AI1=YTOT
C
C       COMPUTE SECOND INTEGRAL
C
      S1=(CO+BO)*X1
      S2=(BO-CO)*X1
      CALL SICI(SI,CI,S1)
      AI2A=DSIN(S1)/X1-(CO+BO)*CI
      CALL SICI(SI,CI,S2)
      AI2B=DSIN(S2)/X1-(BO-CO)*CI
      AI2=AI2A-AI2B
      PHI(MM)=4.0*(AI1+1.0/((1.0+DIEK)*CO*2.0)*AI2)
  908 CONTINUE
      RETURN
      END
      FUNCTION GINT(U)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON /PASS/ R,CO,BO,DIEK
      V=(R-1.0)*U
      W1=CO*U
      W2=DCOSH(U)
      W3=DSINH(U)
      W4=DCOS(BO*U)
      IF(R .NE. 0)W4=W4*DSINH(V)
      IF(R .EQ. 0)DEN=W3+DIEK*W2
      IF(R .NE. 0)DEN=W3*DCOSH(V)+DIEK*W2*DSINH(V)
      GINT=DSIN(W1)/W1*W3/U*W4/DEN
      RETURN
      END
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microstrip	directional coupler
shielded microstrip	characteristic impedance
coupled microstrip	computer-aided design
strip transmission line	microwave integrated circuit

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

MSTRIP has undergone a succession of improvements since its original publication in 1968. Performance of the 1974 and later versions relating to aspects including weakly coupled (<-30 dB) pairs, low shield heights (closer than substrate thickness), and extremely low-impedance lines will be discussed. A FORTRAN list of the 1978 version is appended.

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